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# Analysis of Load Sharing In Femur Implant Using Finite Element Technique

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**ABSTRACT**:
The age related bone loss is a major concern of the older age. The progressive bone loss leads to the weakening of the bone and leads to fractures. The fractures of the femur are the most common problem of the aged population all over the world. Most of the time; the femur implantation surgery is required to be performed in order to repair these fractures. The success of the femur implantation depends on many factors which are of biological and mechanical in nature. The biological problems can be tackled with the help of the drugs whereas mechanical problems such as micro motion of the implant, appropriate selection of the implant, quality of bone bed, implant material etc. requires the pre-fixation analysis so as to suit the patient's requirements. The implant should perform for the life time of the patient hence the durability of implant fixation is very important as the revision surgery becomes critical if the earlier implant selection and fixation is not done properly. The load sharing characteristics of the bone changes with the insertion of the implant. Stiffer implant shares more load and shields the bone from stress; which affects the development of bone. The consequence of stress shielding will lead to further weakening of the bone bed. In this article the effects of various parameters on the load sharing between the bone and implant are studied using finite element technique in order to get the first hand information on the various material and geometric aspects of the implant as well as the bone.

**Keyvwords**: Femur, osteoporotic fracture, finite element method, femur implant, stress shielding

## INTRODUCTION

Osteoporosis disease causes the reduction in the adult bone mass and deterioration of the bone microstructure leading to increase in the bone fragility and susceptibility to fractures. The hip fractures are an important site of the fracture for the older population. The hip fractures seem to increase dramatically after the age of 50 especially in case of women [1]. Since the elderly people are the fastest growing population group in the world [2], the hip fractures prevention and surgeries is going to be a challenging task. The mechanism of the hip fractures in elder people can be usually by fall or physiological overloading. It has been further evident that the lateral fall is the dominant factor as the kinetic energy during the fall is one order higher than the energy required for the fracture of the femur [1, 3]. Most of the times; hip fractures are required to be fitted with the implant. The type of the implant fitment is selected based on the number of factors such as age, quality of the bone bed, previous medical history of the patient, cause of joint failure etc. usually two types of implant fitment techniques are available; either the choice is cemented implant or uncemented implant. Based on the age of the patient the cemented implant is preferred for the elderly patient as the chances of the bone remodelling are comparatively less whereas for the younger patients the uncemented implant fixation is recommended [4]. In both the cases it is very important to select the appropriate implant for the fixation. The mechanical behaviour of the implant is governed by the loading to which the implant is subjected during day to day activities of the patient. The load transfer pattern between the bone and the implant is responsible for the stress shielding. The use of finite element technique presented in this article gives an insight into the stress shielding phenomena which is responsible for the deterioration of the bone bed; which causes the revision surgery more challenging.

## BONE AND IMPLANT MATERIAL PROPERTIES

The human bone can be categorised into two types at the microscopic level, the dense bone as cortical bone and the less dense bone as trabecular bone. The human femur consists of both; the outer one is cortical and the inner one is trabecular. Structurally the cortical bone is compact and 80% to 90% of the volume is calcified whereas only 15% to 20% of trabecular bone is calcified. The cortical bone serves the mechanical purpose of protecting the inner soft bone and tissues whereas the trabecular bone serves the metabolic purpose [5]. The survey of 300 research papers reveals that properties of the cortical and trabecular bone are the function of the apparent bone density [6]. The average value of modulus of the elasticity for both the cortical and trabecular bone is expressed as a power law correlation with the apparent density. The elastic modulus of the cortical bone varies in the range of 11 to 20 GPa [7] whereas for the trabecular bone it is less than the cortical bone.

The hip implant material is required to be bio compatible; meaning that the implant should respond appropriately to a given physiological condition. The implants are meant to stay in the body of the patient for

the either medium term or long term. The implants like bone and joint replacements, dental prosthesis, stents, heart pacemakers and heart valve are expected to stay in the patient's body permanently whereas implants like tissue scaffolds (skin replacement and reconstruction) are made from biodegradable material are medium term implants [8]. The hip joint implant is expected to stay permanently in the human body and also it should be light in weight and it should be strong enough to sustain the physiological load due to daily activities. The various materials satisfy these requirements but most commonly used materials are titanium, cobalt chromium and stainless steel. These materials are biocompatible as well as they have very high mechanical strength and they can be inserted into the human body without any reaction to biological and physiological systems. The mechanical properties of these implant material is as mentioned in the ASTM standard [9] are given in Table1.0

Table1.0 Mechanical properties of implant

| Material | E(GPa) |
|---|---|
| 316L Stainless steel | 190 |
| Cobalt Chromium | 210 |
| Ti-6AL-4V | 116 |

The elastic modulus of the implant varies in the wide range as can be revealed from table1.0. Comparing the stiffness of bone and implant, the elastic modulus of implant is almost ten times more than that of healthy bone. Therefore patient specific selection of the implant becomes a challenging task; as from mechanical aspect; the improper stiffness implant may lead to stiffness incompatibility of bone and implant as a result the long term bonding of implant and bone gets impaired.

**FINITE ELEMENT MODEL OF IMPLANTED FEMUR**

The finite element model of the implanted femur can be made using the layered images from the computed tomography (CT scan data) using the commercially available image processing software. This method is time consuming and requires more computing resources and expertise. Also the parametric variation becomes difficult. In view of this; a simplified model of the implanted femur is used to study the load transfer phenomena. The actual implanted femur is as shown in fig.1.0

To study the mechanical behaviour of the implant; actual model required to be modified in respect of the geometric complexities. The simplifications are proposed with the consideration that the overall mechanics of the load transfer does not get changed. The finite element (FE) model used for the parametric analysis is as shown in fig. 2.

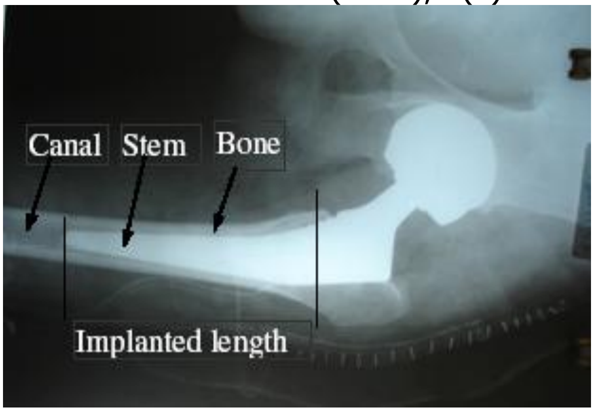


Fig.1.0 Actual implanted femur

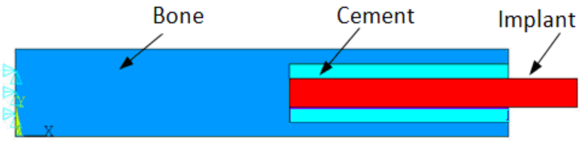


Fig.2.0 FE model of bone and implant (cemented)

The FE models are developed for both cemented and uncemented implant. In the uncemented implant the system is of two components (bone and cement) but in case of cemented implant it becomes the three component system. The size of the implant for the same bone with cemented implant is small compared to uncemented implant. In the cemented system there are two interface surfaces whereas in the uncemented system interface surface is only one.

In both the fitments, the implant is subjected to axial, bending and transverse loads. The magnitude of the load varies depending upon the daily activities of the patient and also with the age and body weight of the patient. The literature mentions a range of about 150 – 450%BW for the peak contact force during level walking and in one case it is even 750%BW. The wide variation in load values suggests that there is no definite value exists for the peak joint contact force [10].The predominant effect of physiological loading is bending [11]. The offset of the femur head leads to more bending load than the axial load. In the present analysis bending load of 5 times the average weight of the person is considered in the parametric model to study the load sharing pattern.

**RESULT OF THE FE ANALYSIS**

The finite element analysis was performed for the cemented and uncemented implant. The averaged outer diameter of the bone is taken 30 mm as the periosteal diameter of 24, 27 and 30 mm represent the small, medium and large bone [4] and the inner bone diameter is taken to be 20mm. The maximum implant size which can be fitted without cement is equal to inner bone diameter. For the finite element analysis the bone, cement and implant are considered to be linear

elastic isotropic material with the transverse load acting at the free stem end of the implant. The finite element analysis is done for the cemented implant having diameter 10mm rigidly fixed. The result of the Von Misses stress distribution for the 10mm size implant is shown infig.3.0

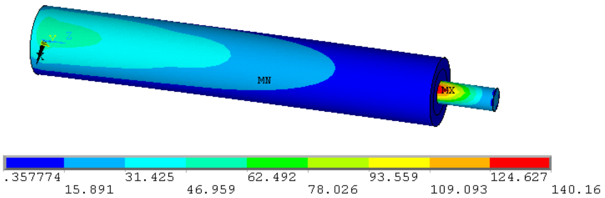

Fig.3.0 FE result of 10mm implant cemented

The results of the above analysis are validated with the analysis result published in literature [12]. The stress in the proximal end of the implant is around 140 MPa as obtained by the analysis matches well with that mentioned in the above cited literature. Also the stress values were marched at the respective locations. The maximum stress is developed in the implant at the proximal end and stress in the bone is less compared to that of in implant. The finite element analysis result indicates that; in the proximal part of the femur, the bone is isolated from the stress; which is called the stress shielding of the bone. The load is transferred at the distal end of the stem which means that the bone is sharing the stress at the distal end. The cut section of the finite element model as shown in fig. 4 reveals that the stem shares maximum stress in the bone implant system.

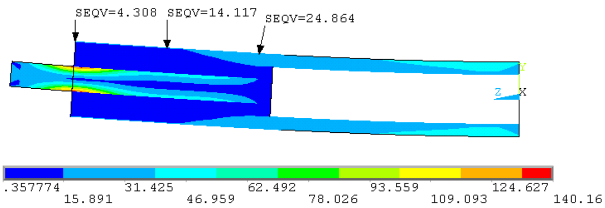

Fig.4.0 FE result of cemented 10mm implant

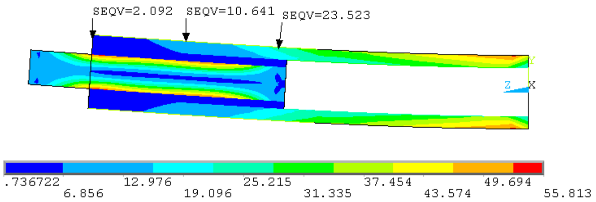

Fig.5.0 FE result of cemented 14mm implant

The FE analysis with the bigger implant size reveals that the overall stress has been reduced drastically but the trend of the stress developed in the bone and the implant remains the same. The stresses developed in the bone for the small size implant and the bigger size implant under the same load and at the same location depicts that the bone shares less stress in the bigger size implant compared to the smaller one as shown in fig. 4 and fig.5.

As can be seen from the analysis the bone gets more shielded from the stress in the proximal part whereas at the distal part the stress is getting transferred to the bone. Invariably the phenomenon is almost similar in the uncemented and cemented bone implant system. Due to this pattern of the load transfer the proximal part of the bone gets thinner and weaker. The clinical findings of the follow-up studies done on 411 patients with the fitment of the hip joint reveal the similar findings of bone loss in the proximal part due to stress shielding [13].

The bone remodelling studies performed by the researcher [14] supports the fact that the proximal part of the femur becomes more critical after the hip joint surgery this is because in the intact femur the complete physiological load is shared by bone alone however due to insertion of the metallic implant the pattern changes adversely in the favour implant being the stiff component. According to the bone remodelling theory the bone remodelling rate is the function of the difference in the stress or strain induced in the intact bone and implanted bone at the same location [14, 15]. In case of implanted femur the metallic component changes the stress pattern; as the bone is sharing less stress; the bone remodelling gets severely affected which leads the bone to fragility and revision surgery becomes even critical. The weakening of the bone is more in the proximal region which shares a very less stress; as a result the proximal part is most adversely affect area of bone bed.

**DISCUSSIONS AND CONCLUSION**

The effect of the implant fitment in the bone is that the proximal part of the femur gets affected badly. The amount of the reduction of the bone stress is more in case of the cementless implant as the implant size is bigger. Also according to the composite beam theory, the load shared by the composite system is proportional to the rigidity of the individual component in which the geometric and material properties play the major role. For the cemented implant fitment the stress shared by bone is more as the implant is relatively small in diameter due to cement layer. Addition of the cement layer between the bone and implant creates additional interface layer which may be prone to increase the chances of failure at the interface. The quality of the bone bed available for implant fitment also affects the stress pattern. It may be noted that the stiff bone shares more load compared to weak bone which changes the choice of implant selection.

In case of the implant fitment, the load sharing is bound to change and the stress shielding is inevitable. As such there is no threshold value exists for the acceptable level of stress shielding, hence the implant dimensions and the material properties are to be selected in such a way that bone load sharing pattern is least affected at the same time implant should be able to sustain the joint load without compromising on its

intended function. The reduction in the implant stiffness reduces the stress shielding hence there is a need to develop strong and flexible implant to minimize the stress shielding problem. The possible solution for this problem may be a composite implant.
In order to select the implant the simplified finite element analysis as presented in this article can provide the meaningful inferences on the mechanical aspects of bone implant system.

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**REFERENCES**

[1] Cordey J., Schneider M., Buhler M.,(2000)The epidemiology of fractures of proximal femur. Injury, Int. J. Care Injured 31, S-C56 -61

[2] Cummins S. R. and Melton L. J., (2002). Epidemiology and outcomes of osteoporotic fractures. Lancet 359,1761-1767

[3] Faulkner K.G., Cummings S.R., Black D., Palermo L., Gluer C.C. Genant H. K. , (1993) Simple measurement of femoral geometry predicts hip fractures: The study of osteoporotic fractures., J. Bone Mineral res.;8,10:1211-1217

[4] Noble P.C., Alexander J.W., Lindhal L.J. Yew D.T., Granberry W. M., and Tullos H.S., (1998) The Anatomic Basis of femoral component design, Clinical Orthop. Rel Res.,No.235, pp.148-165

[5] Roland Baron,(1999) Anatomy and Ultrastructure of bone, Premier on Metabolic Bone Diseases and Disorders of mineral metabolism, 4th edition, American Society of bone and mineral research, pp.3-11

[6] Wirtz D.C., Schiffers N., Pandorf T., Radermacher K., Weichert D.and Forst R., (2000) Critical evaluation of known bone material properties to realize anisotropic FE- simulation of the proximal femur, J. of Biomechanics 33,1325-1330

[7] Currey J. D. , (2001) Ontogenetic changes in compact bone material properties, Bone Mechanics Handbook, second edition , ,CRC Press, NY, pp.19-1 -16

[8] Ramsden J.J., Allen D.M., Stephenson D.J., Alcock J.R.,Peggs G.H., Fuller G. and Goch G., The design and Manufacture of biomedical surfaces, Annals of the CIRP(2007), vol.56, pp.687-711

[9] Medical Devices: Emergency Medical Services and Biomaterial Science: An introduction to materials in Medicine, Annual Book of ASTM standards,1999

[10] Bergman G., Graichen F. and Rohlmann A., (1995), Is staircase walking a risk for the fixation of hip implants?, J. Biomechanics , Vol. 28,No.5, pp.535-553

[11] Huiskes R.,(1994) Various stress patterns of press fit, ingrown and cemented femoral stems, Clinical Orthop. and rel. res., Vol. 261,pp.27-38

[12] Yoon Y.S., Jang G.H. and Kim Y.Y.,(1989),Shape optimal design of the stem of a cemented hip prosthesis to minimize stress concentration in the cement layer, J. biomechanics Vol22,No.11/12, pp.1279-1284

[13] Engh C.A. and Bobyn J.D.(1998), The influence of stem size and extent of porous coating on femoral bone resorption after primary cementless hip arthroplasty, Clinical Orthopaedics and related research,No.231,pp. 7-28

[14] H. Weinans, Huiskes R. and Grootenboer H. J.,(1994) Effects of fit and bonding characteristics of femoral stems on adaptive bone remodelling. Biomechanical Engg. Vol 116,pp. 393-400

[15] Huiseks R. Weinans h and Rietbergen B.V.(1992), The relationship between stress shielding and bone resorption around total hip stems and the effects of flexible materials. Clinical Orthop. Rel Res.,No.274,1992; pp.124-134